Active and Passive Multi-Functional Filtering Circuits Based on Collaborative Techniques

A Dissertation Submitted for the Degree of Doctor of Philosophy

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Jin-Xu Xu declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctoral Degree, in the School of Electrical and Data Engineering, Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution. I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree at any other academic institution except as fully acknowledged within the text. This thesis is the result of a Collaborative Doctoral Research Degree program with South China University of Technology.

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Related Published Works in This Thesis

Since I am in a Collaborative Doctoral Research Degree program with South China University of Technology (SCUT), this thesis includes both the works during my PhD period in UTS and SCUT. The results presented in this thesis discuss both the published works during my PhD candidature in UTS and SCUT, which are detailed as follows.

[1]. J.-X. Xu, H.-Y. Li, X. Y. Zhang, Y. Yang, Q. Xue and E. Dutkiewicz, "Compact dual-channel balanced filter and balun filter based on quad-mode dielectric resonator," *IEEE Trans. Microw. Theory Tech.,* vol. 65, no. 11, pp. 4636-4644, Feb. 2019.

[2]. J.-X. Xu, X. Y. Zhang, H.-Y. Li, Y. Yang, E. Dutkiewicz and Q. Xue, "Ultra-compact multi-channel bandpass filter based on tri-mode dielectric resonator for 5G massive MIMO antenna system," *IEEE Trans. Microw. Theory Tech.,* vol. 68, no. 5, pp. 1668-1677, May 2020.

[3]. J.-X. Xu, X. Y. Zhang, H.-Y. Li, and Y. Yang, "Narrow-band single-pole double throw filtering switch based on dielectric resonator," *IEEE Microw. Wireless Compon. Lett.*, vol. 28, no. 7, pp. 594-596, Jul. 2018.

[4]. J.-X. Xu, L. Yang, Y. Yang, and X. Y. Zhang, "High-Q-factor tunable bandpass filter with constant absolute bandwidth and wide tuning range based on coaxial resonators," *IEEE Trans. Microw. Theory Tech.,* vol. 67, no. 10, pp. 4186-4195, Oct. 2019.

[5]. J.-X. Xu, X. Y. Zhang and Y. Yang, "High-Q-Factor Dual-Band Bandpass Filter and Filtering Switch Using Stub-Loaded Coaxial Resonators," *2019 IEEE MTT-S International Wireless Symposium (IWS)*, Guangzhou, China, 2019, pp. 1-3.

[6]. J.-X. Xu and X. Y. Zhang, "Single- and dual-band LTCC filtering witch with high isolation based on coupling control," *IEEE Trans. Ind. Electron.* vol. 64, no. 4, pp. 3137-3146, Apr. 2017.

[7]. X. Y. Zhang, J.-X. Xu and J. X. Chen, "High-power filtering witch with

low loss and high isolation based on dielectric resonator," *IEEE Trans. Microw. Theory Tech.,* vol. 65, no. 6, pp. 2101-2110, Jun. 2017.

[8]. J.-X. Xu, X. Y. Zhang and X. Q. Song, "High-efficiency filter-integrated class-F power amplifier based on dielectric resonator," *IEEE Microw. Wireless Compon. Lett.*, vol. 27, no. 9, pp. 827-829, Sep. 2017.

[9]. J.-X. Xu, X. Y. Zhang and X. L. Zhao, "Compact LTCC balun with bandpass response based on Marchand balun," *IEEE Microw. Wireless Compon. Lett.*, vol. 26, no. 7, pp. 493-495, Jul. 2016.

[10]. J.-X. Xu and X. Y. Zhang, "Compact high-isolation LTCC diplexer using common stub-loaded resonator with controllable frequencies and bandwidths," *IEEE Trans. Microw. Theory Tech.,* vol. 67, no. 2, pp. 494-504, Nov. 2017.

[11]. J.-X. Xu, X. Y. Zhang and H.-Y. Li, "Compact narrow-band filtering rat-race coupler using quad-mode dielectric resonator," *IEEE Trans. Microw. Theory Tech.,* vol. 66, no. 9, pp. 4029-4039, Sep. 2018.

[12]. J.-X. Xu and X. Y. Zhang, "Dual-channel dielectric resonator filter and its application to Doherty power amplifier for 5G massive MIMO system," *IEEE Trans. Microw. Theory Tech.,* vol. 66, no. 7, pp. 3297-3305, Jul. 2018.

Abstract

In radio frequency front ends, there are lots of active and passive circuits, such as filters, power amplifiers (PAs), switches, couplers and so on. Generally, they are cascaded in wireless systems, which suffer from the large size, high loss, or efficiency degradation due to impedance mismatching. To solve these problems, novel methods for collaborative designs of multiple circuits are proposed, and overall performance is improved by the complementation of different circuits. Design methods for fusion of multiple circuits are also proposed by constructing one circuit function into another circuit, which can simplify the structures to reduce the size and loss. Lots of active and passive multi-functional filtering circuits are proposed, including the following three sections:

1. To improve overall efficiency of the PA, switch, and filter, integration of filters and active circuits are conducted. To reduce the total loss and improve isolation of the switch and filter, coupling control method is proposed to fuse the functions of filter and switch. To avoid efficiency degradation by impedance mismatching, the collaborative design of a class-F PA and a high-selectivity filter is presented.

2. To reduce the loss and size, filters are integrated with other passive circuits. The functions of a balun circuit and a rat-race coupler are fused to a filter to realize the miniaturized filtering balun and filtering rat-race coupler, respectively. By using a common dual-mode resonator, a compact LTCC diplexer with controllable frequencies and bandwidths is designed.

3. For high integration, dual-/multi-channel filtering circuits are proposed. Based on a quad-mode dielectric resonator, two filters are integrated as one dual-channel filter, and then collaborative-designed with a two-input two-output Doherty PA for high integration and high efficiency. For further integration, multi-channel filters and dual-channel balanced/balun filters are also proposed.

In this thesis, design methods and working mechanisms of proposed multi-functional filtering circuits are detailed. Measured results are given to show the validity of the proposed designs. As compared to reported designs or products from

some international companies, the proposed designs show advantages of miniaturization or low power consumption, which are useful in wireless applications.

Keywords: Active multi-functional filtering circuit, filtering switch, filtering power amplifier, passive multi-functional filtering circuit, multi-channel filtering circuit, collaborative-design

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Jinxu Xu

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